

Assessment and Management of Ganga River Water Quality Using Multivariate Statistical Techniques in India

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Received January 28, 2015; revised and accepted October 3, 2015

Abstract: Multivariate statistical techniques, such as cluster analysis and principal component analysis (PCA), were applied for evaluation of spatial variations and interpretation of large complex water quality data set of the Ganga river basin, generated during one year (2013-2014) monitoring of eight water parameters at seven different sites. Hierarchical cluster analysis grouped seven sampling sites into three clusters, i.e., relatively low polluted (LP), medium polluted (MP) and highly polluted (HP) sites based on the similarity of water quality characteristics. Principal component analysis produced three significant main components and explaining more than 82.9% of the variance (anthropogenic and industrial effect) that present 57.1%, 13.8% and 12% respectively of the total variance of water quality in Ganga river. The result reveals that Turbidity, Dissolved oxygen and Biochemical oxygen demand are the parameters that are most important in assessing variations of water quality. Water quality index based on eight parameters (Turbidity, DO, BOD, COD, pH, TS, TSS and TDS) calculated for all the sites are found to be medium to bad. Thus, this study illustrates the usefulness of multivariate statistical techniques for analysis, interpretation of complex data sets and understanding spatial variations in water quality for effective river water quality management. The study reveals that untreated industrial and municipal discharges are the major source of the pollution to the Ganga river. Implementation of suitable management plan along with proper sewerage treatment network, maintaining sufficient dilution flow, artificial aeration and watershed management will control the pollution in the Ganga river.

Key words: Ganga river basin, water quality index, cluster analysis, principal component analysis.

Introduction

Rivers have been an integral part of human element right since the dawn of civilization. The Ganga is largest basin of the Indian subcontinent. River is a system comprising the main course and the tributaries, the flow of which carrying a significant load of matter in dissolved and particulate phases from both natural and anthropogenic sources. These days in view of increasing population, urbanisation and industrialisation, the rivers and the streams are often being treated as detriment disposal site for various municipal and industrial wastes causing greatest detriment to health of the various

rivers. The quality of a river at any location reflects several major influences, including the lithology of the river basin, atmospheric inputs, climatic conditions and anthropogenic activities (Bricker and Jones, 1995).

Contrary to this, rivers play an important role in assimilation or transportation of municipal and industrial waste water and runoff from agriculture land. Municipal waste water and industrial effluent discharge constitute constant polluting sources, whereas surface runoff is a seasonal phenomenon, largely affected by non-point source pollution which seems to be climatic conditions within the river basin (Singh et al., 2004).

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Such type of problems may be worsened as seasonal variations of groundwater flow, precipitation, interflow, water pumped inflow and outflow and runoff through surface have an adverse effect on river discharge as well as on the concentration of pollutants in the river water quality (Vega et al., 1998). The river is currently facing heavy soil erosion at its river basin and at some places it becomes shallow.

Solid waste that has been continuously thrown into the river is very visible at all major cities. The landfill site located near river basin directly affects the water quality. The other sources of pollutants include effluent from NTPC plant, BHEL, pulp & paper, tannery, food and beverage industry. The long-term management of river requires basic understanding of chemical, biological and hydrological characteristics. Since, spatial variation of the water quality is difficult to interpret, a monitoring programme is often necessary which has responsibility to provide representative and reliable estimation of the river water quality (Dixon and Chis-well, 1996). The chemometric technique approach such as multivariate analysis like cluster analysis (CA), principal component analysis (PCA) and water quality index for analysis of the complex data sets provides a reliable and better understanding of the hydrological processes in the study area.

These statistical methods permit identification of the factors which influence more the water quality river system. Such type of analysis techniques have been proved to be valuable tool for developing effective strategies for management of the water system as well as provide quick solution to pollution problems. In addition to this multivariate statistical analysis can also help in verifying spatial variations caused by natural and anthropogenic factors linked with seasonality. The multivariate statistical analysis has been successfully applied in a number of research articles till the year (Simeonov et al., 2003, 2004; Vega et al., 1998; Kowalkowskia et al., 2006; Yang et al., 2009; H. Boyacioglu, 2008; Singh et al., 2004, 2005; Lee et al., 2001; Adams et al., 2001; Wunderline et al., 2001; Reghunath et al., 2002; Juahir et al., 2010; Otto et al., 1998; Johnson et al., 1992; Samsudin et al., 2011).

The data matrix obtained during one year study programme is subjected to multivariate statistical technique to extract hidden information about the similarities or dissimilarities between sampling sites, identification of water quality variables responsible for spatial variations in water quality, and the influence of possible natural and anthropogenic sources on the water quality parameters of the Ganga basin. The several

problems focused in this study has made it necessary for planners to study the impact of different kinds of pollutants that have been continuously discharged into river in unmannered way and then apply best available methodology to manage the river water quality so that its quality does not degrade below the prescribed limit (Singh et al., 2007).

Sources of Pollution of Ganga River

1. River Ramganga and Kali are the major tributaries of river Ganga which are also source of major pollution. These rivers merge with the Ganga with pollution load 235 MLD and 595 MLD respectively in the vicinity of Kannauj district of Uttar Pradesh having significant number of grossly polluting industries impacting their water quality.
2. One hundred and thirty eight main drains carrying industrial as well as domestic waste water with an average BOD load 999 tons/day and an average flow rate of 6087 MLD meet the river Ganga its traverse through Uttrakhand, Uttar Pradesh, Bihar and West Bengal.
3. Millions of the people come to take a holy dip into the river all the year round. As a result bacteriological contamination increases.
4. River water is also polluted further directly or indirectly as there are no regular crematoria, dumping ponds for holy offerings and dhobhi ghats.
5. The run-off from the agriculture area within the catchment of river basin further aggravates the problem.

Materials and Methods

Study Area

The Ganga River originates from the Garhwal of the Himalaya (30° 55' N, 79° 7' E) with the name Bhagirathi. The traditional source of Ganga river is identified as ice-cave of Gaumukh at the snout of the Gangotri glacier which is 4100 metres above the sea level. The river makes its path through Himalayas and flows a distance of about 2525 kms covering entire state of Uttarakhand, Uttar Pradesh, Bihar, and West Bengal. Basin of the Ganga river accounts for a little more than one-fourth (26.3%) of the India's total geographical area and is the biggest river basin in country. The Ganga river has many tributaries and distributaries. Some of them are Kali, Ramganga, Yamuna, Gomati, Ghaghra, Gandak and Kosi etc. and the main plateau river tributaries are Tons, Son,

Damodar and Kangsbasti-Haldi. In the present study, an analysis has been carried out for seven cities which are chosen as sampling stations. These sampling locations (Figure 1) are: Haridwar (29.93°N, 78.17°E), Kanpur (26.46°N, 80.33°E), Fatehpur (25.93°N, 80.80°E), Kaushambi (25.53° N, 53° E), Allahabad (25.45° N, 81.85° E), Mirzapur (25.15° N, 82.60° E) and Varanasi (25.28° N, 82.95° E).

Monitored Parameters and Analytical Methods

The data set of seven water quality monitoring stations, comprising eight water quality parameters were monitored on monthly basis over one year study period. Although 50 water quality parameters are available, only eight parameters were selected due to their regularity in measurement at all selected water quality monitoring stations (Figure 2). The selected water quality parameters include turbidity, dissolved

oxygen, biochemical oxygen demand, chemical oxygen demand, pH, total dissolved solids, total suspended solids and total solids. Standard APHA method is used for the examination of water.

Multivariate Statistical Methods

River water quality and source identification were performed using two multivariate statistical techniques such as cluster analysis and principal component analysis. All mathematical computations were made using Microsoft Office 2010 and MINITAB 14.

Cluster Analysis

Cluster analysis is an exploratory data analysis method, whose primary purpose is to assemble objects based on the characteristics they possess, which can be independently applied for pattern recognition. Cluster analysis classifies objects in such a way that each object



Figure 1: Map of study area showing the different sampling stations.

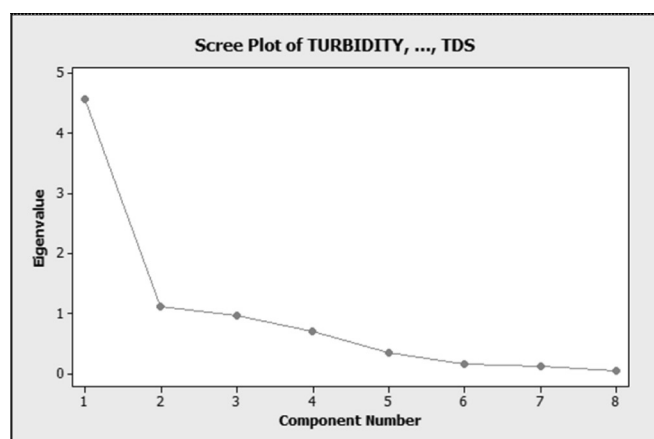


Figure 2: Scree plot of eight water quality parameters.

is similar to the others in the cluster with respect to predefined selection criteria. The resulting clusters of objects may then exhibit high internal homogeneity (within cluster) and high external heterogeneity. The hierarchical agglomerative clustering is the common a step by step approach, which is used to provide intuitive similarity relationship between any one sample to the entire other data set. The result of clustering is illustrated by a dendrogram (tree diagram) (Figure 3) (McKenna, 2003).

The dendrogram reduces dimensionality of data set and provides picture of the groups and their proximity which can easily interpret summary of the clustering processes (Otto, 1998; Gupta et al., 2013). In this study,

sets without minimum loss of original information (Helena et al., 2000). The principal component analysis is applied to normalised data variables to extract significant principal components and to further reduce the contribution of variables (Vega et al., 1998; Helene et al., 2000; Brumelis et al., 2000; Singh et al., 2004, 2005; Love et al., 2004; Abdul-Wahab et al., 2005). To interpret and describe the variation in water quality of Ganga river, principal component analysis (PCA) is being used in this study. The principal component can be expressed as:

$$Z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} \dots + a_{im}x_{mj}$$

where z is the component score, a is the component loading, x the measured value of variable, i is the component number, j the sample number and m the total number of variables.

Water Quality Index

The water samples from river were collected on monthly basis as per the standard method of APHA (2005). In this study, for the calculation of water quality index, three important parameters, which have more importance on variance of water quality as shown by PCA (Harkins, 1974; Tiwari et al., 1986; Mohanta and Patra, 2000; Padmanabh and Belagalli, 2005) are chosen for analysis of water quality index. The WQI has been calculated by using the standard of drinking water quality as recommended by the World Health Organization (WHO).

$$\text{Water quality index (WQI)} = \sum_{i=1}^p W_i q_i$$

where p = Number of water quality parameters, W_i = Weight in terms of importance associated with water quality parameter and q_i = Sub index for the i^{th} water quality parameters.

$$q_i = \frac{100(V_a - V_i)}{(V_s - V_i)}$$

V_a = Actual values present in the water sample, V_i = Ideal value (0 for all parameters except pH and DO which are 7.0 and 14.6 mg/l respectively) and V_s = Standard value.

If $q_i = 0$ means complete absence of pollutants. While $0 < q_i < 100$ implies that the pollution level is within the prescribed standard. When $q_i > 100$ indicates that the pollutants are above the standards (Mohanty, 2004).

Results and Discussion

A boxplot or box-and-whisker diagram or plot is a convenient way of graphically depicting group of

numerical data through their five number summaries: the minimum, lower quartile, median, upper quartile and sample maximum. A box plot may also indicate which observations may be considered outliers. The ends of the whiskers represent the minimum and maximum of all the data. The bottom and top of the box is the 25th and 75th percentile. Any data not included between the whiskers is plotted as an outlier with a small circle or star. Turbidity has four sampling months as outlier with small star, the sampling months are May, June, and August (Kanpur) and July (Allahabad). Dissolved oxygen has December (Haridwar) month as outlier. The BOD has two months as outlier; these are January (Haridwar) and August (Kanpur). Three outliers are found in COD Box Plot; these are January (Haridwar), July and August (Kanpur). The pH has no months as outlier. The total solids have outlier in months June (Kanpur, Allahabad, Mirzapur, Varanasi), July (Kanpur, Allahabad, Mirzapur, Varanasi) and August (Kanpur, Varanasi). The total suspended solids have following outlier: June (Kanpur, Allahabad, Mirzapur, Varanasi) and July (Kanpur). The total dissolved solids have outlier in two months; these are June (Kanpur, Allahabad, Mirzapur, Varanasi) and July (Kanpur, Allahabad, Varanasi).

Water Quality Index

Average water quality index as shown in Table 1, of seven sampling sites varied between less polluted, moderate polluted and very high polluted. Haridwar is found to be less polluted; Fatehpur, Kaushambi, Allahabad, Mirzapur and Varanasi are found to be moderate polluted; and Kanpur is found to be high polluted.

Cluster Analysis

Minitab displays the amalgamation steps in the session window. At each step, two clusters are joined. The minitab summarizes each cluster by the number of observations, within the cluster sum of squares, average distance from observation to the cluster centroid, and maximum distance of observation to the cluster centroid. The centroid is the vector of variable means for the observations in that cluster and is used as a cluster midpoint, also shows centroids for the individual clusters. The dendrogram displays the information in the amalgamation table in the form of a tree diagram.

From the dendrogram as shown in Figure 3, cluster 1 consists of 15 months which were relatively less polluted. Inclusion of the three months (Jan, Feb and Dec.) of Kaushambi from the middle downstream

Table 1: Month-wise water quality index from year 2013-14

<i>Months</i>	<i>Water quality index in year</i>						
	<i>Haridwar</i>	<i>Kanpur</i>	<i>Fatehpur</i>	<i>Kaushambi</i>	<i>Allahabad</i>	<i>Mirzapur</i>	<i>Varanasi</i>
January	24	118	107	97	115	109	116
February	48	161	123	93	150	145	141
March	78	215	211	69	204	196	199
April	95	322	169	152	287	218	240
May	90	464	231	191	290	222	235
June	119	416	221	203	301	233	262
July	102	264	271	213	258	253	307
August	132	490	276	224	229	238	260
September	106	284	279	226	235	266	205
October	102	294	240	217	221	223	195
November	80	194	201	186	158	136	177
December	51	170	124	110	149	141	149
Water quality	Less polluted	High polluted	Moderate polluted	Moderate polluted	Moderate polluted	Moderate polluted	Moderate polluted

of sampling location in cluster 1, suggests the self-purification and assimilative capacity of the Ganga river. Cluster 2 comprised 56 months which are moderately polluted. These stations receive pollution mostly from domestic waste water, waste water treatment plants and industrial effluents located in the city areas. Cluster 3 comprised 13 monitoring months highly polluted and these stations receive pollution load mostly from non-point sources, municipal sewage treatment plants and industrial discharge. During these months high level of pollution is observed due to low flow of the Ganga river. It is very clear from the dendrogram that pollution level is less during winter seasons as compared to summer seasons. The result of water quality index and those of cluster analysis almost match because water quality index and cluster analysis uses the same parameters of seven cities of the Ganga river for one year duration. The results indicate that the cluster analysis technique is useful in offering reliable classification of the Ganga river quality parameters and will make it possible to design a future spatial sampling strategy in an optimal manner, which can reduce the number of sampling stations and associated costs.

Principal Component Analysis

The first principal component, as given in Table 2, has variance (Eigenvalue) 4.5689 and account for 57.1% of the total variance. The coefficients listed under PC1 in Table 3 shows how to calculate the principal component scores:

$$PC1 = -0.378Tur. -0.067DO-0.0420BOD-0.390COD+0.102pH-0.422TS-0.392TSS-0.427TDS$$

It should be noted that the interpretation of the principal components is subjective. For example the principal component can be considered as representing an overall Turbidity, DO, BOD, COD, TS, TSS and TDS, because the coefficients of these terms have same sign and are not close to zero. The second principal component has variance 1.1079 and accounts for 13.8% of the data variability. It is calculated from the original data using the coefficients listed under PC2. Together, the first two and first three components represent 70.9% and 82.97% of the data variability respectively, of the total variability. Thus most of the data structure can be captured in two or three underlying dimensions. The remaining principal components account for a very small proportion of the variability and are probably unimportant. The scree plot as shown in Figure 3, provides this information visually.

The principal component analysis is applied to standardized log transformed data. Only the Eigen values greater than 1 are considered essential. The first factor which explained 57.8% of the total variance has strong positive load on pH which may be interpreted as pollution. The second factor which explains 13.8% of the variance have strong positive loading on DO, pH, TS, TSS and TDS which may be interpreted as presence of carbonic pollution. The principal component analysis result shows that four physico-chemical parameters (pH, TS, TSS and TDS) are identified as less important in

Table 2: Eigen analysis of the correlation matrix

	<i>PC1</i>	<i>PC2</i>	<i>PC3</i>	<i>PC4</i>	<i>PC5</i>	<i>PC6</i>	<i>PC7</i>	<i>PC8</i>
Eigenvalues	4.5689	1.1079	0.9608	0.6912	0.3406	0.1586	0.1214	0.0507
Proportion	0.571	0.138	0.120	0.086	0.043	0.020	0.015	0.006
Cumulative	0.571	0.710	0.830	0.916	0.959	0.978	0.994	1.000

Table 3: Correlation matrix of principal component analysis

<i>Variable</i>	<i>PC1</i>	<i>PC2</i>	<i>PC3</i>	<i>PC4</i>	<i>PC5</i>	<i>PC6</i>	<i>PC7</i>	<i>PC8</i>
Turbidity	-0.378	-0.257	0.065	-0.170	0.856	-0.004	0.059	-0.146
DO	-0.067	0.780	-0.424	-0.425	0.158	-0.034	-0.039	0.017
BOD	-0.420	-0.144	0.026	-0.346	-0.374	-0.037	-0.471	-0.606
COD	-0.390	-0.225	0.017	-0.509	-0.296	0.082	0.480	0.463
pH	0.120	0.361	0.895	-0.235	0.038	0.041	-0.006	-0.006
TS	-0.422	0.131	0.106	0.276	-0.040	-0.770	-0.178	0.303
TSS	-0.392	0.299	0.041	0.448	-0.107	0.139	0.598	-0.408
TDS	-0.427	0.134	0.040	0.283	0.002	0.614	-0.449	0.374

explaining the annual variance of data set, and therefore could be non-principal parameters. It must be noticed that only one year annual mean values of data set of water quality parameters are used in this study. Before making any decision in eliminating water quality parameter of Ganga river, the PCA with three or more years can be considered.

Conclusions

The Ganga river seems to be dying slow death because millions of tons of untreated domestic and industrial waste water flows into the river daily. The Ganga river suffers from myriad problems, the lean flow during dry season is one of the most significant factor. The diversion of Ganga river water through upper and lower Ganga canals that leave virtually very small flow in the main stem of the Ganga river which makes dilution difficult even if the treated sewage waste water is discharged. From the study it is found that there is need of sewage treatment plants and availability of proper conveyance system for sewage in whole stretch of Ganga river basin in Uttar Pradesh. This is also noticed that there is need of minimum ecological flow for its survival in the stretch of Uttar Pradesh. As the river is considered as a living eco-system, ultimate goal must be made to protect the proper functioning of the Ganga river eco-system. Major industrial sectors such as tannery, sugar and distillery, pulp and paper mill contribute significant pollution load to the Ganga river

and its tributaries. The industries discharging their solid and liquid wastes into the Ganga must be directed to follow best available practices for managing solid and liquid wastes and attain complete recycling of water and proper disposal of waste as per norms enforced by the regulating authorities.

The water quality of the Ganga river can be improved to some level if immediate firm environmental surveillance is applied in order to check their compliance with environmental standards. The present infrastructure is not at all adequate to abate the pollution. The Ganga river water is mostly used for bathing purposes. In many months of study period the Ganga water is found not fit even for bathing. The strategies for resuscitating water quality of the Ganga river may include defensive and proactive approaches. Improvement in sewage network, enhancing sewage treatment capacities and preventing pollution load coming from tributaries are the measures under defensive approach which should be urgently executed. The construction of barrage on Ganga river, and tributaries rivers seems to be suitable option for reducing the concentration of pollution on Ganga river. The term measure approaches must be implemented to reduce non-point sources pollution. Due to indiscriminate use of chemical fertilizers, nutrients like N, P and K reaches to water body leading to algal bloom. A layer of algae is often seen on the surface of the Ganga river during post rainy season. The farmers in the catchment area of Ganga river basin must be educated to avoid indiscriminate use of chemical

fertilizers and pesticides etc. Measures like wetlands and riparian zones may be developed as a long-term strategy to abate entry of nutrients.

It is also noticed that due to improper system of waste collection, heaps of solid waste are often seen at various sites; as a result, of leachate from solid waste leads to Ganga river water contaminate. At present cremation is done on the river bed itself nearly at all ghats of the Ganga river and people directly throw ashes into the Ganga river. There is a need to construct improved wood based crematoria and needs to educate people to use electric crematoria. As a result of religious convictions people use to dump holy materials and offerings of puja into the Ganga river, which remains floating on the surface creating an ugly scene. This problem can be solved by constructing holy pond at a suitable site which may be filled by the Ganga river water. Afforestation should be developed on the whole catchment area along the banks of Ganga river. This will help to reduce soil erosion as well as air pollution and will prevent entry of silt, nutrients and pesticides into the Ganga river. For this purpose authors would like to suggest Banyan tree for planting along the bank of river as this has long life and high soil binding capacity.

There must be legislation and fines to the specific industry and assimilative capacity of the Ganga river. Industries or municipalities violating effluent standards must be penalized and this also be imposed on general public if they are found polluting the Ganga river. There is an urgent need to maintain minimum dilution flow in the river. This may be achieved either through construction of dam or by proper watershed management. Aeration with some expenditure will help in improving the Ganga water quality. This can be obtained either by providing diffused aeration or mechanical surface aerator. It is realised that rapid increase in population also affects the Ganga river water as new colonies are developed without proper sanitation and treatment capacities. Thus these newly developed colonies start discharging their waste water directly into the Ganga river. Thus it is concluded that there is a need of active participation of all people to resuscitate the Ganga river, which can be achieved by education and awareness of the people.

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New Journal Information

Journal of Climate Change

We are proud to announce the launch of **Journal of Climate Change** from July 2015. The purpose of the journal is to provide a platform to exchange ideas among those working in different disciplines related to climatic variations. The journal also plans to create an interdisciplinary forum for discussion of evidence of climate change, its causes, its natural resource impacts and its human impacts. The journal will also explore technological, policy, economy, strategic and social responses to climate change. It will be peer-reviewed, supported by rigorous processes of criterion-referenced article ranking and qualitative commentary, ensuring that only standard accepted quality work of the greatest substance and highest significance is published.

Journal of Climatic Change intends to publish most complete and reliable source of information on the discoveries and current developments in the mode of original articles, review articles, case reports, short communications, etc. in all areas of the field.

Themes intended to be covered:

*Climate Systems and Sustainable Development*Pollution, Climate Change, Risk Assessment, and Human Health*Green technology and Climate Change Impact*Climate Change Impacts on Cryosphere, and Water Resources Systems*Water Sustainability (Surface and ground water) and Climate Change*Agricultural Sustainability and Climate Change*Urban Sustainability and Storm water Management under Changing Climate*Mitigation and Adaptation of Climate Change by Green Production, Pollution Prevention and Control*Dynamics of Coupled Natural and Human Systems Under Climate Change Impacts*Unique Interactions between the Environmental System, Climate Change, Land Use, Ecosystem Function and Services*Modeling approach to mitigate and understand the climate change

The Journal is co-published with IOS Press, The Netherlands for outside the SAARC region.

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